M 564/3/987

Preprint from the 1987

BUREAU OF MINES MINERALS YEARBOOK

Other Metals

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNITED STATES DEPARTMENT OF THE INTERIOR • Donald Paul Hodel, Secretary

BUREAU OF MINES • T S Ary, Director

This publication is a chapter from the current Bureau of Mines Minerals Yearbook, comprising *Volume I, Metals and Minerals; Volume II, Area Reports: Domestic; Volume III, Area Reports: International.* The separate volumes of the Yearbook are sold by the Superintendent of Documents, Washington, D.C. 20402.

Other Metals

By Staff, Branches of Nonferrous and Ferrous Metals

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ARSENIC[1]

ASARCO Incorporated, the only domestic arsenic producer, terminated copper-smelting operations and the associated recovery of byproduct arsenic trioxide at Tacoma, WA, in 1985. It still shipped small quantities of trioxide from its remaining stocks in 1987. Imports for consumption of arsenic trioxide were slightly higher than in 1986.

Domestic Data Coverage.—Shipments of small amounts of arsenic trioxide from remaining stocks by Asarco were reported voluntarily to the Bureau of Mines.

Legislation and Government Programs.—The Environmental Protection Agency (EPA) issued its preliminary position to cancel most of the nonwood pesticide uses for inorganic arsenicals. Included in the list were lead arsenate, calcium arsenate, sodium arsenite, sodium arsenate, and arsenic trioxide. Exceptions to the list were turf herbicidal use of the flowable formulation of calcium arsenate, the grapefruit growth regulator use of lead arsenate, and the grape fungicidal use of sodium arsenite. These three uses and the desiccant use of arsenic acid were still under special review by EPA. All copper acetoarsenite and arsenic acid herbicide registrations had already been voluntarily canceled. The EPA invited comments on the proposal.[2]

Life Systems Inc., under contract for the U.S. Public Health Service, published a toxicological profile for arsenic, which was made available for public comment. Toxicological data and the regulatory status of arsenic were discussed.[3]

DOMESTIC PRODUCTION

Asarco shipped small quantities of arsenic trioxide to customers from the remaining stocks at its closed copper smelter in Tacoma, WA. Koppers Co. Inc. in Conley, GA, a major producer of arsenical wood preservatives, produced arsenic trioxide, which it converted to arsenic acid. The acid was marketed or consumed internally in the production of chromated copper arsenate wood preservatives. The Applied Research Group, Charlotte, NC, and Hickory Grove Industries, Hickory Grove, SC, both owned by Hickson Inc., United Kingdom, produced arsenic acid for use in the wood industry. In addition, Mineral Research Development Corp., Harrisburg, NC, and Chemical Specialties Inc., Valdosta, GA, both owned by LaPorte Industries PLC, United Kingdom, also produced arsenic acid for use in the wood industry. W. R. Metals Inc. in Wheat Ridge, CO, produced arsenic acid in Wyoming from arsenic-bearing lead smelter flue dusts containing about 50% arsenic.

CONSUMPTION AND USES

Arsenic compounds, principally arsenic trioxide, accounted for 98% of the arsenic consumed in 1987. Demand for arsenic was about the same level in 1987 as it was in 1986. The wood industry continued to be the dominant industry using trioxide. The estimated end-use distribution of arsenic (metal contents) was 69% in wood preservatives, 20% in agricultural products (principally herbicides and desiccants), 4% in glass, 2% in metallic form in nonferrous alloys and electronics, and 5% in other uses (animal feed additives, pharmaceuticals, etc.).

The bulk of metallic arsenic was used in lead- and copper-base alloys as a minor additive (about 0.01% to 0.5%) to increase strength in the posts and grids of lead-acid storage batteries and to improve corrosion resistance and tensile strength in copper alloys. A relatively small amount of high-purity arsenic metal, about 15 metric tons, was used in the electronics industry. Gallium arsenide and its alloys have been used in products such as light-emitting diodes and displays, room-temperature lasers, microwave devices, solar cells, and photoemissive surfaces. Gallium arsenide integrated circuits are currently undergoing commercial development, and, compared with silicon circuits, have higher operating frequencies, lower power consumption, lower noise, and superior resistance to radiation damage. Because of these superior properties, they are expected to have extensive military and commercial applications.

PRICES

Prices for imported refined arsenic trioxide from Mexico remained constant throughout the year at $0.44 per pound. This was the only price quoted by Metals Week.

Table 1.—Arsenic price quotations

(Cents per pound, yearend)

	1985	1986	1987
Trioxide, domestic, 99% As$_2$O$_3$, f.o.b. Tacoma, WA[1]	32	32	e/
Trioxide, Mexican, 99.13% As$_2$O$_3$, f.o.b. Laredo, TX[2]	42	44	44
Metal, domestic, 99% As[3]	210	165	e/

e/ Discontinued.
1Price suspended.
2Metals Week.

Table 2.—U.S. imports for consumption of arsenicals, by class and country

Class and country	1985		1986		1987	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Arsenic trioxide:						
Argentina	20	$3				
Belgium-Luxembourg	1,459	1,974	1,250	$967	1,942	$1,555
Bolivia	38	97			16	13
Canada	3,982	4,300	2,424	1,811	2,512	788
Chile	191	161	1,503	797	4,400	1,925
China	100	49	59	26	250	126
France	3,808	3,284	6,274	4,972	6,241	2,740
Germany, Federal Republic of			200	165		
Hong Kong					38	15
India					261	97
Japan	971	784	141	74	45	22
Korea, Republic of					102	70
Mexico	3,388	2,946	4,406	3,431	4,407	2,550
Namibia			304	224	92	40
Netherlands	196	145				
Philippines	25	12	300	150	1,280	429
Portugal	15	12	99	75		
Saudi Arabia			90	52		
South Africa, Republic of	123	92	1,010	475	1,200	442
Sweden	2,900	3,014	1,369	1,341	4,924	4,410
Switzerland					301	265
Trinidad and Tobago	136	88	136	80	90	52
Total[1]	18,473	16,998	20,156	15,847	28,540	13,900

1Data may not add to totals shown.

Table 2.—U.S. imports for consumption of arsenicals, by class and country —Continued

Class and country	1985		1986		1987	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Arsenic acid:						
Australia	--	--	--	--	16	$28
Germany, Federal Republic of	--	--	(2)	$1	--	--
United Kingdom	1,993	$1,360	1,381	999	1,038	824
Total	1,993	1,360	1,381	1,000	1,054	852
Arsenic sulfide:						
Germany, Federal Republic of	--	--	--	--	15	10
Philippines	2	2	--	--	--	--
Sweden	--	--	16	2	--	--
United Kingdom	--	--	(2)	12	--	--
Total	2	2	16	14	15	10
Arsenic metal:						
Belgium-Luxembourg	--	--	--	--	2	18
Canada	23	644	8	731	16	1,054
China	136	311	295	951	463	972
Dominica	--	--	--	--	(2)	1
Germany, Federal Republic of	2	195	7	272	2	174
Hong Kong	47	158	34	115	139	291
Japan	22	171	2	382	9	951
Netherlands	--	--	(2)	4	--	--
Sweden	171	642	34	124	(2)	1
Switzerland	--	--	10	53	--	--
Taiwan	5	17	--	--	--	--
United Kingdom	(2)	12	5	17	(2)	8
Total[1]	407	2,150	395	2,649	631	3,471
Lead arsenate:						
Canada	29	13	--	--	--	--
Germany, Federal Republic of	--	--	6	56	--	--
Japan	(2)	1	--	--	--	--
Netherlands	66	128	--	--	--	--
Peru	68	144	--	--	--	--
United Kingdom	--	--	60	114	50	95
Total[1]	162	287	66	170	50	95
Sodium arsenate:						
France	20	7	--	--	421	72
Israel	--	--	--	--	--	--
Other	(2)	3	--	--	--	--
Total	20	10	--	--	421	72
Arsenic compounds, n.s.p.f.:						
Brazil	--	--	9	482	--	--
Canada	--	--	(2)	1	--	--
Mexico	23	52	--	--	--	--
United Kingdom	(2)	66	(2)	175	(2)	41
Other	(2)	13	(2)	13	(2)	42
Total[1]	23	131	10	671	(2)	83

[1]Data may not add to totals shown because of independent rounding.
[2]Less than 1/2 unit.

Source: Bureau of the Census.

WORLD REVIEW

Arsenic is recovered as arsenic trioxide in about 20 countries from the smelting or roasting of nonferrous metal ores or concentrates. Arsenic metal, which accounts for only 3% of world demand for arsenic, is produced by the reduction of arsenic trioxide. Commercial-grade arsenic metal, which is 99%-pure arsenic, is produced in only a few countries. This grade accounts for the majority of arsenic metal production. High-purity arsenic, which is 99.99% pure or greater and is used in the semiconductor industry, is produced by about 10 companies. Furukawa Co. Ltd. in Japan and Preussag AG in the Federal Republic of Germany are believed to be the world's largest producers, with reported metal production capacities of 30 tons and 15 tons per year, respectively. Other high-purity arsenic producers include Cominco Ltd. in Canada; Mitsubishi Metal Corp. and Rasa Industries Co. Ltd. in Japan; and Johnson Matthey PLC and MCP Electronic Materials Ltd. in the United Kingdom.

Table 3.—Arsenic trioxide:[1] World production, by country[2]

(Metric tons)

Country[3]	1983	1984	1985	1986[p]	1987[e]
Belgium[e]	3,009	3,000	3,000	3,000	3,500
Bolivia	107	144	361	241	130
Canada[e 4]	2,000	3,000	3,000	3,000	3,000
Chile[e 5]	--	3,500	4,000	6,000	5,000
France	4,727	3,828	[r]8,000	[r]10,000	9,000
Germany, Federal Republic of[e]	360	360	360	360	360
Japan[e]	300	500	500	500	500
Korea, Republic of	560	NA	NA	NA	100
Mexico	4,557	5,496	6,312	7,016	7,000
Namibia[e]	1,126	2,504	2,471	1,936	1,800
Peru[7]	1,009	1,090	1,257	[r]1,210	1,200
Philippines[e 8]	--	--	5,000	5,000	5,000
Portugal[e]	180	180	170	150	150
Sweden[e 9]	9,000	10,000	10,000	10,000	10,000
U.S.S.R.[e]	7,300	8,000	8,100	8,100	8,100
United States	7,300	6,800	2,200	--	--
Total	42,126	48,402	54,731	56,513	54,840

[e]Estimated. [p]Preliminary. NA Not available.

[1]Including calculated arsenic trioxide equivalent of output of elemental arsenic and arsenic compounds other than arsenic trioxide where inclusion of such materials would not duplicate reported arsenic trioxide production.

[2]Table includes data available through June 10, 1988.

[3]Austria, China, Czechoslovakia, the German Democratic Republic, Hungary, Spain, the United Kingdom, and Yugoslavia have produced arsenic and/or arsenic compounds in previous years, but information is inadequate to make reliable estimates of output levels, if any.

[4]Figures include estimated production of low-grade dusts that were exported to the United States for further refining.

[5]Chile began producing arsenic trioxide during 1983 from the El Indio gold-copper ores, however, it was not of marketable quality and required further refining by foreign producers. It has not been listed separately to avoid double counting.

[6]Output of Tsumeb Corp. Ltd. only.

[7]Output of Empresa Minera del Centro del Perú (Centromin Perú) as reported by the Ministerio de Energía y Minas.

[8]The Philippines may have had some arsenic output in 1984 from the Philippine Smelting and Refining Corp. (PASAR) copper smelter, but available information is inadequate to make reliable estimates of output levels, if any.

[9]Based on arsenic trioxide exported plus the arsenic trioxide equivalent of the output of metallic arsenic exported.

CESIUM AND RUBIDIUM[4]

Domestic data for cesium and rubidium are developed by the Bureau of Mines from a voluntary survey of U.S. operations. Of the four operations to which a survey request was sent, two companies responded; production data are withheld to avoid disclosing company proprietary data. Cesium and rubidium metals and compounds were produced from pollucite and lepidolite ores imported from Canada. The metals were produced by the Electronic Materials and Refractory Metals Div. of Cabot Corp., Revere, PA. Cabot also produced cesium and rubidium compounds. The Special Products Div. of Carus Chemical Co., LaSalle, IL, produced cesium compounds. Cabot's prices for cesium and rubidium materials in quantities under 50 pounds remained unchanged from its 1986 prices. Per pound quotes to the nearest dollar for technical grades and high-purity grades, the latter in parentheses, were as follows: cesium metal $275 ($325), rubidium metal $300 ($375), common cesium compounds $36 to $44 ($73 to $79), and common rubidium compounds $104 to $112 ($155 to $170).

Japan's Matsushita Electric Co. reportedly developed a new paper-thin rubidium-containing electrolyte suitable for use in devices such as batteries, chemical sensors, and pacemakers; it is light, and operates over a relatively wide range of temperatures, -60° C to 100° C.[5]

Table 4.—U.S. imports for consumption of cesium compounds, by class and country

Class and country	1985		1986		1987	
	Quantity (pounds)	Value	Quantity (pounds)	Value	Quantity (pounds)	Value
Cesium chloride:						
Canada	--	--	--	--	31,445	$2,667,401
Germany, Federal Republic of	20,452	$630,635	27,924	$952,998	29,098	1,078,217
Netherlands	33	1,897	44	2,639	--	--
Norway	362	11,335	210	12,187	345	14,986
Sweden	115	7,367	124	9,096	8	1,110
United Kingdom	192	5,464	--	--	352	12,557
Total	21,154	656,688	28,302	976,920	61,248	3,774,271
Cesium compounds, n.s.p.f.:						
German Democratic Republic	119	2,625	--	--	--	--
Germany, Federal Republic of	28,358	735,785	7,140	165,717	12,500	241,659
Greece	110	2,726	--	--	4,783	--
Italy	--	--	--	82	--	--
Japan	170	32,250	1,984	5,821	--	--
Netherlands	--	--	58	11,390	62	12,214
United Kingdom	626	164,468	3	1,076	--	--
Total	29,383	937,854	9,185	184,004	12,644	258,656

Source: Bureau of the Census.

GERMANIUM[e]

The estimated domestic production and consumption of germanium increased compared with that of 1986. Infrared systems and fiber optics continued to be the major end uses. The domestic fiber-optic market decreased for the second successive year, and germanium consumption for fiber optics also declined. The National Defense Stockpile (NDS) goal for germanium was increased substantially. Germanium is a strategic material that is vital to the manufacture of infrared systems needed by advanced aircraft and other defense applications.

Domestic Data Coverage.—Domestic refinery production and consumption data for germanium are estimated by the Bureau of Mines based on discussions with domestic producers.

Legislation and Government Programs.—Pursuant to section 3 of the Strategic and Critical Materials Stock Piling Act (50 U.S.C. 98 and following) and Executive Order 12155, the Federal Emergency Management Agency determined that, effective July 24, 1987, the NDS goal for germanium was increased from 30,000 kilograms to 146,000 kilograms, where it remained at yearend.[r]

The General Services Administration (GSA) began the purchase of zone-refined germanium metal for the NDS. During the two initial rounds that took place in May and August, the GSA was successful in the purchase of 7,000 kilograms of metal. The first-round puchase price was at $666 per kilogram, and the second was at $731 per kilogram. In September, the GSA contracted to purchase 23,000 kilograms of germanium during the third round of bidding to meet the previous 30,000-kilogram goal for the NDS. Tightening of supplies, probably owing in part to the GSA purchases, led to prices of $740 to $784 per kilogram for this round. In an effort not to disrupt the market, delivery times were stretched out to August 1989. The free-market price increased from a range of $700 to $800 per kilogram to about $825 per kilogram when GSA began awarding the contracts. All of the contract prices were considerably below the U.S. published price. Germanium was expected to come from Belgium, France, and the United States to satisfy these contracts.

Although metal transactions were conducted during the year, deliveries were not made, and no stocks of germanium were reported by GSA at yearend.

DOMESTIC PRODUCTION

Domestic refinery production from both primary and secondary materials was estimated to be 25,000 kilograms. Refined germanium products were produced by Eagle-Picher Industries Inc., Quapaw, OK; KBI Div. of Cabot, Revere, PA; and Atomergic Chemetals Corp., Plainview, NY.

The Jersey Minière Zinc Co. in Clarksville, TN. continued to produce germanium-

rich residues as a byproduct of processing zinc ores from its Gordonsville and Elmwood Mines. These residues reportedly were shipped to Métallurgie Hoboken-Overpelt S.A. (MHO) in Belgium for germanium recovery and refining.

Lack of working capital and technical problems with its leach extraction unit reportedly caused Musto Exploration Ltd. to temporarily close its Apex Mine and refinery operation at St. George, UT, as of September 1987. Company officials indicated that the facilities would remain closed for more than 4 months. During the closure, the company planned to make required equipment repairs and to continue its metallurgical test work to increase overall recoveries for both germanium and gallium. Musto Exploration was the only company in the world to recover germanium and gallium as principal products.

CONSUMPTION AND USES

The consumption of germanium was estimated at 40,000 kilograms, a slight increase compared with that of 1986. The estimated consumption pattern by end use of germanium in 1987 was as follows: infrared systems, 65%; fiber optics, 10%; gamma-ray, X-ray, and infrared detectors, 6%; semiconductors, 5%; and other, 14%.

The largest end use for germanium continued to be in infrared optics, mainly for military use in guidance and weapon-sighting systems. Germanium-containing lenses and windows transmit thermal radiation similar to visible light transmission by optical glass. Germanium glass was also used for nonmilitary surveillance and monitoring systems in fields such as satellite systems and fire alarms.

The U.S. fiber-optic market continued the downward trend started in 1986. Consumption of germanium in this application decreased about 17% compared with that of 1986. Many of the long-distance fiber-optic telecommunication systems have been completed and others are planned for installation in the future. However, fiber-optic applications for local-area-network systems were becoming a reality and reportedly offered the most effective means of transmitting voice and data with immunity to electromagnetic and noise interference. Optical signals cannot be intercepted easily, and they provide a more secure system. These attributes and the light weight of fibers compared with conventional communication systems make fiber optics an ideal system for military and civilian applications.

PRICES

The domestic producer prices, published by Metals Week, for germanium metal and germanium dioxide remained at $1,060 and $660 per kilogram, respectively.

The Belgian producer prices, published by Metal Bulletin (London), for germanium metal and germanium dioxide began the year at $1,116 and $676 per kilogram, respectively.[6] On February 11, the prices decreased to $795 per kilogram for germanium metal and $455 per kilogram for germanium dioxide. The Belgian producer prices remained at these levels through yearend.

FOREIGN TRADE

A comparison of the value per kilogram of imported germanium material with the published foreign producer price for germanium metal, before estimated processing charges, was used to estimate the germanium content of imported scrap. In 1987, the estimated germanium content of total imports was calculated to be approximately 13,000 kilograms.

Table 5.—U.S. imports for consumption of germanium, by class and country

Class and country	1986		1987	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Unwrought and waste and scrap:				
Belgium-Luxembourg	833	$850,804	1,401	$1,455,925
Canada	21	17,058	35	22,903
China	6,296	2,746,121	5,168	2,402,457
France	19	16,590	5,448	2,737,307
Germany, Federal Republic of	137	197,860	1,121	755,366
Hong Kong	489	209,186	549	240,630
India	85	13,337	--	--

Table 5.—U.S. imports for consumption of germanium, by class and country —Continued

Class and country	1986		1987	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Unwrought and waste and scrap —Continued				
Israel	195	$38,948	195	$5,985
Italy	542	30,063	--	--
Japan	--	--	15	23,415
Netherlands	889	85,757	--	--
Sweden	179	127,806	--	--
Switzerland	45	10,490	391	46,588
Taiwan	213	89,329	--	--
United Kingdom	--	--	686	296,238
Total	9,943	4,433,349	15,009	7,986,814
Wrought:				
Belgium-Luxembourg	2,347	2,726,407	1,340	1,348,383
China	198	73,856	--	--
France	8	1,315	--	--
Germany, Federal Republic of	415	290,640	584	652,902
Israel	--	--	549	499,518
Netherlands	--	--	16	3,496
Total	2,968	3,092,218	2,489	2,504,299

Source: Bureau of the Census

WORLD REVIEW

Australia.—The Overseas Telecommunications Commission called for vendors to submit bids for the installation of an underwater fiber-optic cable system. This long-distance network system is the first phase of the previously announced Tasman II fiber-optic system, which will link Australia to New Zealand by 1991, North America by 1993, and Asia by 1995.[9]

Japan.—Germanium metal production decreased dramatically from 8,810 kilograms to 4,637 kilograms. Germanium dioxide production was 13,358 kilograms, which was equivalent to that of 1986.[10]

Spain.—Asturiana de Zinc S.A. sold its first lot of 1,200 kilograms of germanium concentrates derived from processing zinc concentrates from the La Troya Mine, Guipézcoa, Spain. The mine is owned by Exminesa, a consortium including Asturiana, Banco Urquijo, Cominco, and Union Corp. It was expected to produce 40,000 tons of zinc and 6,000 kilograms of germanium per year.

U.S.S.R.—Unlike market economy countries, which produce germanium as a by-product of the refining of base metal ores, the U.S.S.R. reportedly recovered germanium from coal tar and coking residues generated by coking coal from the Donetsk Basin in the Ukraine. Also under consideration was the recovery of germanium from fly ash generated in powerplants, possibly using an extraction technique similar to that used in the United Kingdom prior to the mid-1970's.

TECHNOLOGY

The Bureau of Mines investigated pressure-leaching techniques for recovering gallium and germanium from low-grade ores and zinc-processing residue samples. Detailed studies were made on an ore sample obtained from the Apex Mine, St. George, UT, which contained 0.033% gallium and 0.096% germanium. Pressure leaching of this ore sample at 200° C for 3 hours, coextracted 93% of the gallium and 96% of the germanium when the sulfur dioxide used in the reactor was greater than 2,200 pounds per short ton of treated ore. Selective extraction of 91% to 96% germanium was obtained using less than 1,500 pounds of sulfur dioxide per short ton of treated ore.[11]

Development of high-strength optical fibers and related components for wide-bandwidth two-way telecommunications have paved the way for fiber-optic guided missile systems. In these systems, many miles of spooled fiber, carried aboard a missile, are played out to maintain two-way communication between the missile and the launcher during the flight time. Numerous flights of this type of weapon system successfully demonstrated its target accuracy against both tanks and airborne helicopters.[12]

INDIUM[1][2]

Indium was produced by the Arconium Corp., Providence, RI, and Indium Corp. of America, Utica, NY. Domestic production in 1987 increased slightly more than that of 1986, and imports maintained a significant market share. The Bureau of Mines does not publish domestic production data on indium. Small quantities of secondary indium were available from specialty-metal-recycling firms. The potential for the use of indium in advanced materials was increased through research on component chemicals for coatings and solar cells.

CONSUMPTION AND USES

Indium usage increased in 1987. Consumption in the categories of fusible alloys and solders remained strong. Consumption for nuclear control rods remained low, essentially at a replacement level. Research continued on a broad range of possible new applications, especially for high-performance solders, for solar cells, and an indium-tin oxide coating for flat glass that would be transparent to visible light, electrically conductive, and would prevent entry of infrared rays. Estimated consumption patterns for indium metal were solder, alloys, and coatings, 50%; electrical and electronic components, 35%; and research and other uses, 15%.

PRICES

The producer price of indium, published in Metals Week, was $2.87 per troy ounce at the beginning of 1987. It increased steadily throughout the first 7 months to $9.95 per troy ounce in July, at which level it remained until yearend. The sharp price rise during 1987 was attributed by industry analysts to strong demand in Japan, particularly for liquid crystal displays.

Table 6.—U.S. imports for consumption of indium, by class and country

(Thousand troy ounces and thousand dollars)

Class and country	1985		1986		1987	
	Quantity	Value	Quantity	Value	Quantity	Value
Unwrought and waste and scrap:						
Belgium-Luxembourg	99	257	313	751	335	1,994
Canada	16	100	41	107	43	286
China	128	423	218	520	148	903
France	140	308	113	411	341	1,614
Germany, Federal Republic of	2	30	2	50	9	102
Hong Kong	19	50	26	72	15	144
Italy	259	596	331	759	185	1,121
Jamaica	(3)	17				
Japan	2	43	6	104	29	478
Netherlands	16	67	23	50	46	219
Peru	111	260	60	139	102	643
Switzerland	16	36	8	17		
United Kingdom	147	1,009	221	1,159	262	1,887
Total[2]	955	3,197	1,362	4,138	1,515	9,421
Wrought:						
China			9	21	(3)	17
France	19	90				
Germany, Federal Republic of	(3)	3	1	9		
Japan	3	60	1	70	1	61
United Kingdom	3	124	6	440	5	297
Other	(3)	6	(3)	7		
Total[2]	25	283	18	495	7	375

[1]Less than 1/2 unit.
[2]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

WORLD REVIEW

World production increased slightly to an estimated 2.5 million troy ounces. A world supply shortage existed primarily due to strong demand from Japan.

Major world refiners included Cominco in Canada; MHO in Belgium; Penarroya in France and Italy; Dowa Mining Co. Ltd. and Mitsui Mining & Smelting Co. Ltd. in Japan; Minero Perú Comercial in Peru; Mining and Chemical Products Ltd. in the United Kingdom; and Government metallurgical complexes in China and the U.S.S.R.

TECHNOLOGY

Research in Japan developed a new direct synthesis technique for making indium phosphide. In this method, liquid phosphorus was utilized instead of the normal phosphorus gas. During the phase transition of phosphorus from liquid to gas and then gas to liquid, the liquid phosphorus reacts with indium to produce indium phosphide of a very high-purity crystalline structure. This development may enhance the application of indium phosphide in commercial use in such areas as solar cells and laser diodes for fiber optics.[14]

Research in Taiwan resulted in direct deposition of the transparent conductor indium-tin-oxide by direct thermal evaporation of metallic indium and tin in an ambient oxygen environment. The key point in reducing the resistivity of the indium-tin-oxide film apparently was to control the tin-to-indium weight ratio to an optimum value of 3 to 1. These findings may enhance commercialization of a range of possible applications for indium coatings on glass and other surfaces.[15]

RHENIUM[16]

Cyprus Minerals Co. was the only domestic producer to recover rhenium in 1987. Rhenium contained in molybdenite was mined as a byproduct of porphyry copper ore from seven mines in the Southwestern United States. Consumption of rhenium increased about 19% in 1987. Imports for consumption decreased about 17%. The major use continued to be bimetallic platinum-rhenium catalysts to produce lead-free gasoline. The price of rhenium metal increased to $500 per pound in 1987 from $350 in 1986, and the price of ammonium perrhenate remained at $200 per pound.

Domestic Data Coverage.—Domestic mine production data for rhenium are developed by the Bureau of Mines from the reported molybdenum production at the seven operating porphyry-copper-molybdenum-rhenium mines in the United States.

Table 7.—Salient U.S. rhenium statistics

(Pounds of contained rhenium)

	1983	1984	1985	1986	1987
Mine production[1]	r16,900	r17,300	r21,100	r21,700	21,800
Recovered[2]	W	W	W	W	W
Consumption[r]	8,860	10,200	12,000	14,000	15,500
Imports (metal)	623	1,962	4,913	5,495	r7,436
Imports for consumption of ammonium perrhenate	5,947	4,754	3,825	r12,189	7,225
Stocks, Dec. 31	W	W	W	W	W

[r]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data.
[1]Calculated rhenium contained in MoS_2 concentrates.
[2]In prior years, this was shown as mine production.

FOREIGN TRADE

Imports for consumption decreased as a whole, but rhenium in the form of metal increased. Most of the ammonium-perrhenate was received from Chile, the Federal Republic of Germany, and Sweden. Chile and the Federal Republic of Germany supplied the rhenium metal.

World production of rhenium was estimated to be 40,000 pounds, exclusive of U.S. production. Rhenium was recovered from byproduct molybdenite concentrates from porphyry copper deposits in Canada, Chile, China, Iran, Peru, the U.S.S.R., and the United States. In addition, the U.S.S.R. also recovered rhenium as a byproduct from the Dzhezkazgan sedimentary copper deposit in Kazakhstan. Rhenium metal and compounds were recovered from molybdenum

concentrates in Chile, France, the Federal Republic of Germany, Sweden, the U.S.S.R., the United Kingdom, and the United States. Chile's recovery of rhenium was the largest amount produced by a market economy country.

Table 8.—U.S. import duties for rhenium materials

Item	TSUS No.	Most favored nation (MFN) Jan. 1, 1987	Non-MFN Jan. 1, 1987
Unwrought metal	628.9000	3.7% ad valorem	25% ad valorem.
Wrought metal	628.9500	5.5% ad valorem	45% ad valorem.
Ammonium perrhenate	417.4520	3.1% ad valorem	25% ad valorem.
Perrhenic acid	416.4540	4.2% ad valorem	Do.

Table 9.—U.S. imports for consumption of ammonium perrhenate, by country

(Rhenium content)

Country	1985		1986		1987	
	Quantity (pounds)	Value (thousands)	Quantity (pounds)	Value (thousands)	Quantity (pounds)	Value (thousands)
Belgium-Luxembourg	--	--	76	$22	--	--
Brazil	--	--	1,022	175	70	$27
Chile	2,918	$611	8,360	r1,502	4,906	1,426
China	--	--	--	--	4	2
Ecuador	--	--	--	--	154	61
Germany, Federal Republic of	407	58	r1,938	r352	547	176
Japan	--	--	158	28	209	89
Netherlands	--	--	635	120	--	--
Sweden	--	--	--	--	1,040	272
United Kingdom	--	--	--	--	295	69
Total	3,325	669	r12,189	r2,199	7,225	2,122

rRevised.

Source: Bureau of the Census.

Table 10.—U.S. imports for consumption of rhenium metal, by country

Country	1985		1986		1987	
	Gross weight (pounds)	Value	Gross weight (pounds)	Value	Gross weight (pounds)	Value
Chile	3,300	$825,000	3,150	$2,014,000	5,463	$1,445,045
Germany, Federal Republic of	1,424	337,662	1,904	432,000	1,867	593,093
United Kingdom	193	54,065	441	171,000	--	--
Other[1]	27	8,378	--	--	106	34,343
Total	4,943	1,225,105	5,495	2,617,000	7,436	2,072,480

[1]Includes Haiti, Sweden, Switzerland, and Uruguay.

Source: Bureau of the Census.

SCANDIUM[17]

Production of refined scandium in the United States increased. Most of the scandium processed in the United States in 1987 was derived from previously mined domestic ores and concentrates. Demand for scandium for use in laser crystals and special-use light bulbs, its principal markets, increased slightly. Scandium was obtained as a byproduct from tungsten concentrates, fluorite tailings, and uranium solutions at three locations in the Western United States. The uranium-scandium mine source which had ceased operating in 1985, reopened in 1987. As an advanced material scandium-containing synthetic garnet crystals were components in high-energy lasers.

Domestic Data Coverage.—Domestic production data for scandium are estimated by the Bureau of Mines on the basis of discussions with domestic producers, processors and consumers.

DOMESTIC PRODUCTION

Byproduct scandium-bearing ore and concentrate from three domestic mines were processed in 1987. Bingham Canyon was the only domestic mine operating in 1987 that produced ore containing byproduct scandium. As a result of scandium's high cost, the industry is reportedly investigating methods to economically recover scandium from scrap materials, principally laser rods.

Energy Fuels Nuclear Inc. produced scandium concentrate as a byproduct of uranium processing. Ore for Energy Fuels Nuclear's plant was derived as a byproduct of copper recovered by leaching at Kennecott's Bingham Canyon Mine, Bingham Canyon, UT. Energy Fuels Nuclear purchased the Bingham Canyon uranium-scandium recovery facility in 1986 from Westinghouse Electric Corp. and reopened the plant in February 1987. Prior to its purchase, Westinghouse had ceased operation of the plant in August 1985.

Refined scandium products, principally scandium oxide, were produced domestically by Baldwin Metal Processing Co., Phoenix, AZ; Boulder Scientific Co., Mead, CO; Materials Preparation Center, Ames, IA; Research Chemicals Div. of Nucor Corp., Phoenix, AZ; and Sausville Chemical Co. Inc., Garfield, NJ.

Refined scandium was recovered by Baldwin Metal Processing Co. from residual fluorite screenings accumulated at an inactive fluorite mine at Crystal Mountain, MT. By yearend, Baldwin Metal had reportedly closed its processing operations. Boulder Scientific produced scandium from previously mined tungsten concentrates derived from the processing of molybdenum ores at AMAX Inc.'s Climax Mine, Climax, CO, and from scandium concentrates produced by Energy Fuels Nuclear's uranium facility at Bingham Canyon, UT. AMAX's molybdenum and byproduct tungsten operations at Climax closed in mid-1986 and were kept on a maintenance basis throughout 1987.

Scandium was also refined by Sausville Chemical from scandium concentrate produced at Bingham Canyon, UT.

CONSUMPTION AND USES

Domestic consumption of scandium in 1987 was estimated at 66 kilograms of equivalent scandium oxide, an increase of 15 kilograms from the estimated quantity consumed in 1986. The major use for scandium was in laser crystals of gadolinium-scandium-gallium garnets (GSGG), which were used in high-average-energy laser systems. GSGG laser crystals are more than twice as energy efficient as yttrium-aluminum garnets as a lasing medium. Laser applications for GSGG are in communications and high-average-energy (not pulsed) applications such as hydrogen fusion research and antimissile defense systems, and in lower energy lasers used in medical, electronic, and industrial applications.

Scandium is used in high-intensity mercury vapor lights to produce a highly efficient, near-sunlight color emission that is used for indoor and outdoor nighttime lighting to simulate daylight for color television broadcast. Three to five milligrams of scandium are added per bulb.

The radioactive isotope scandium-46 was used as a tracing agent in petroleum refineries and in oil wells.

Scandium metal, backed by molybdenum, was used in dual anode tubes in X-ray fluorescence spectrometers. Excitation efficiency of the dual anode system is reportedly excellent in detection of the light elements through titanium.

Small amounts of scandium metal reportedly were used in semiconductors, while minor amounts found use in petroleum catalysts and collimators in neutron lenses.

Additions of scandium to titanium carbide reportedly create a binary carbide with a hardness close to that of diamond.

PRICES

No published prices for scandium were available. Yearend nominal prices for scandium oxide per kilogram, compiled by the Bureau of Mines from information from several suppliers, were as follows: 98% purity, $6,500; 99% purity, $7,000; 99.9% purity, $9,500; 99.99% purity, $11,000; 99.995% purity, $13,000; 99.999% purity, $15,000. Scandium metal prices varied considerably, depending on the quantity of material being purchased and its purity.

FOREIGN TRADE

No trade data were available for scandium as an individual item. However, analysis of small shipments of high value from probable scandium import sources suggested that about 2 kilograms of scandium oxide was imported from the United Kingdom.

Based on data compiled by the Bureau of Mines, the United States was a net exporter

of scandium in 1987 and is no longer dependent on foreign sources for its current demands.

WORLD REVIEW

Foreign countries that mined scandium in 1987 included Australia, China, Norway, and the U.S.S.R. Refined scandium was processed in France, Japan, Norway, and the United Kingdom.

A/S Megon announced the opening of a scandium oxide processing pilot plant in June at Norway's Institute of Energy, near Oslo. The plant, which was scheduled to open in June, has a planned capacity of 10 kilograms of scandium oxide per month. The opening of the plant coincides with the discovery of two scandium-rich deposits in Finnmark County in northern Norway, and at Evje, 50 kilometers northwest of Kristiansand, in the south.[18]

TECHNOLOGY

Scandium and rare-earth elements in Jamaican bauxite wastes were characterized by researchers at the University of the West Indies, Kingston, Jamaica. The red mud waste generated by processing Jamaican bauxite by the Bayer process was determined to be enriched with scandium, compared with the ore. Scandium oxide contents of 200 to 390 parts per million were detected in the bauxite wastes at a uniform rate of distribution.[19]

Developers at Mitsubishi have added scandium oxide to the cathode ray tubes (CRT) of certain rear-projection, big-screen televisions. The addition of scandium oxide reportedly blocks the formation of a reactant on the cathodes oxide layer, allowing increased electron beam output and improved longevity of the CRT.[20]

SELENIUM[21]

Domestic output of refined selenium, a byproduct of copper refining, increased by about 50%. One domestic producer resumed production at its refinery, which had been closed since 1985, and the two other producers increased their production. Despite the increase in domestic production, the United States continued to rely heavily on imports, which met most of the domestic demand.

Apparent consumption of refined selenium rose about 10%, reflecting increased agricultural use and an increase in the production of photoreceptors for plain paper copiers, the largest use for refined selenium. With world demand exceeding production, the price of selenium rose steadily throughout the year.

Domestic Data Coverage.—Domestic data for selenium are developed by the Bureau of Mines from a voluntary survey of stocks, production, and shipments at the three U.S. producers. All three producers responded to the survey. Data are withheld to avoid disclosing company proprietary information.

Table 11.—Salient selenium statistics

(Kilograms of contained selenium unless otherwise specified)

	1983	1984	1985	1986	1987
United States:					
Production, primary refined	352,860	288,886	W	W	W
Shipments to consumers	374,030	224,401	W	W	W
Exports, metal, waste and scrap	93,368	122,329	154,122	161,007	162,217
Imports for consumption	297,029	376,946	400,658	462,646	495,862
Consumption, apparent	577,691	478,418	W	W	W
Stocks, Dec. 31: Producers[1]	152,790	139,159	W	W	W
Dealers' price, average per pound, commercial-grade[2]	$3.87	$9.02	r$7.44	r$5.70	$6.51
World: Refinery production	r1,402,992	r1,493,851	1,324,756	p1,193,744	r1,245,059

eEstimated. pPreliminary. rRevised. W Withheld to avoid disclosing company proprietary data.

[1]Granular selenium, a semirefined form of selenium, is included in stocks.

[2]Metals Week. 1985-87 calculated from published price ranges.

Legislation and Government Programs.—In April, the Food and Drug Administration, U.S. Department of Health and Human Services, published new regulations concerning the use of selenium as an additive in feed for major food-producing animals. The new regulations allow for an increase in the maximum supplementation level of selenium in "complete" feed from 0.1 to 0.3 part per million, as well as proportional increases in separate feed supplements and salt-mineral mixtures. This action was in response to a petition filed in 1986 by the American Feed Industry Association Inc.[2]

DOMESTIC PRODUCTION

Primary selenium was recovered as a byproduct of the electrolytic refining of copper. Selenium, along with precious metals, accumulates in anode slimes generated in the electrolytic cells.

Primary selenium was recovered by three domestic copper refiners: Asarco at Amarillo, TX; Phelps Dodge Refining Corp. at El Paso, TX; and BP Minerals America Corp. (formerly Kennecott) at Magna, UT. Production at the Magna refinery, which had been closed since 1985, resumed during the third quarter of the year. Selenium-bearing anode slimes from other domestic copper refineries were either shipped to one of the above refineries or exported for processing.

Production of refined selenium increased 50% despite an increase of only 4% in electrolytic copper production. Responding to higher prices, producers sought to increase production of refined selenium by maximizing their recovery of selenium from anode slimes and by processing accumulated stocks of crude selenium into refined material. However, shipments by domestic producers increased by only 15%, as producers sought to replenish depleted stocks, possibly in anticipation of further price increases.

Most selenium of domestic origin was produced as commercial-grade selenium, averaging 99.5% selenium, and available as powder, shot or small lumps, and pigment-grade selenium powder, with a minimum 99.8% purity. A small quantity of high-grade selenium, with a minimum 99.99% selenium content, and ferroselenium, were also produced.

About 100 tons of selenium contained in scrap derived from the manufacture of photocopier drums and from used photocopier drums was exported for processing.

CONSUMPTION AND USES

Consumption of selenium increased by more than 10% in 1987, as a result of demand in a strong agricultural market and the effects of a weakened U.S. dollar. Demand for selenium by end use was estimated as follows: electronic and photocopier components, 43%; pigments and chemicals, 20%; glass manufacturing, 20%; and other, including agriculture and metallurgy, 17%.

The major demand for selenium in the electronics end-use sector was as a photoreceptor on the drums of plain-paper electrophotographic copiers. This end use contributed significantly to the growth in U.S. demand, with several Japanese manufacturers having established production facilities in the United States and world demand for photoreceptors having grown at about 5% per year. Agricultural use of selenium, where sodium selenate or selenite was used as feed additives or nutritional supplements to compensate for animal feed grown in selenium-deficient soil, increased significantly in response to new Food and Drug Administration regulations increasing the allowable supplemental levels. Most of the domestic demand in this sector was met by imports.

In the glass industry, selenium was used primarily in the production of container glass as a decolorant. It was also used in architectural glass to reduce solar-heat transmission. Selenium-bearing cadmium sulfoselenide red pigments were used as colorants for plastics, glass, and ceramics.

PRICES

The price of selenium, which had been depressed throughout 1986, rose steadily during 1987 in response to declining stock levels and world demand in excess of production. The New York dealer price range for commercial-grade selenium, quoted by Metals Week on a weekly basis, began the year at $5.40 to $5.65 per pound and rose steadily to $9.00 to $9.50 per pound at yearend. The free-market European price followed the same pattern.

FOREIGN TRADE

Total imports for consumption of selenium, as measured in terms of contained selenium, rose for the fourth consecutive year, to a level about two-thirds above the 1983 level. The strength of imports was tied to the high domestic industrial demand stimulated by the weakened U.S. dollar, and to new regulations governing agricultural usage. Total exports were at about the same level as in 1986; about two-thirds of the exports was scrap.

Table 12.—U.S. exports of selenium metal, waste and scrap, by country

Country	1985		1986		1987	
	Quantity (kilograms, contained selenium)	Value	Quantity (kilograms, contained selenium)	Value	Quantity (kilograms, contained selenium)	Value
Argentina	1,179	$22,750	2,907	$44,163	998	$10,704
Australia	962	29,220	--	--	17,941	140,504
Belgium-Luxembourg	--	--	--	--	59	3,250
Brazil	650	10,400	319	5,099	2,772	44,307
Canada	2,207	40,595	324	5,171	1,955	28,290
China	--	--	--	--	--	--
Colombia	894	22,660	7,387	144,870	1,159	18,526
France	318	5,075	1,011	16,150	--	--
Germany, Federal Republic of	7,861	126,793	--	--	299	4,280
India	68	4,765	--	--	34,611	270,252
Italy	1,456	20,015	1,883	21,835	1,031	21,662
Japan	36,951	289,592	42,875	245,381	--	--
Korea, Republic of	45	1,800	10,165	52,265	30,385	462,450
Malaysia	--	--	4,802	76,752	7,484	83,160
Mexico	19,265	308,481	15,231	237,033	9,072	6,000
Netherlands	7,711	106,360	19,421	180,238	1,014	12,258
Norway	236	6,760	--	--	51,246	546,020
Philippines	18,144	42,000	17,178	43,486	1,814	28,987
Portugal	91	1,950	272	3,350	377	5,520
Spain	--	--	--	--	--	--
Switzerland	4,990	75,350	2,984	32,763	--	--
United Kingdom	51,096	316,177	34,200	342,461	--	--
Venezuela	--	--	48	1,446	--	--
Other	--	--	--	--	--	--
Total[1]	154,122	1,430,743	161,007	1,452,463	162,217	1,686,180

[1]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

Table 13.—U.S. imports for consumption of selenium, by class and country

Class and country	1985		1986		1987	
	Quantity (kilograms, contained selenium)	Value	Quantity (kilograms, contained selenium)	Value	Quantity (kilograms, contained selenium)	Value
Unwrought and waste and scrap:						
Belgium-Luxembourg	63,353	$1,572,220	86,143	$2,736,960	94,477	$2,649,893
Canada	111,927	2,353,429	130,038	2,886,721	136,621	2,784,833
Chile	7,500	153,902	3,000	42,118	--	--
China	--	--	--	--	4,475	47,503
Costa Rica	--	--	362	11,940	--	--
Finland	--	--	--	--	1,000	13,302
German Democratic Republic	45	14,743	--	--	--	--
Germany, Federal Republic of	5,550	126,877	205	9,496	1,940	25,767
Japan	72,609	2,056,694	87,858	1,958,821	85,657	1,789,989
Korea, Republic of	--	--	2,000	19,852	1,500	13,524
Netherlands	15,239	30,851	3,680	61,216	--	--
Philippines	16,748	243,747	10,000	86,200	12,000	111,667
Sweden	100	3,750	--	--	--	--
United Kingdom	66,434	910,947	97,408	1,501,694	76,379	1,245,330
Yugoslavia	--	--	5,000	43,572	20,000	153,657
Total	359,505	7,467,160	425,694	8,858,590	434,049	8,805,465
Selenium dioxide:						
Belgium-Luxembourg	--	--	8	1,011	--	--
Germany, Federal Republic of	6,916	164,471	5,405	113,472	3,594	70,990
Japan	--	--	--	--	6,227	138,782
United Kingdom	--	--	142	3,114	1,314	29,724
Total	6,916	164,471	5,555	117,597	11,135	239,496
Selenium salts:						
Belgium-Luxembourg	567	29,839	--	--	46	1,233
France	4,847	4,962	1,626	2,662	--	--
Korea, Republic of	7,000	114,959	650	7,798	300	7,677
United Kingdom	--	--	--	--	--	--
Total	12,414	149,760	2,276	10,460	346	8,910

Table 13.—U.S. imports for consumption of selenium, by class and country —Continued

Class and country	1985		1986		1987	
	Quantity (kilograms, contained selenium)	Value	Quantity (kilograms, contained selenium)	Value	Quantity (kilograms, contained selenium)	Value
Sodium selenite:						
Belgium-Luxembourg	--	--	--	--	230	$5,550
Canada	42	$2,090	4	$1,648	345	8,454
Germany, Federal Republic of	3,013	80,091	14,987	125,108	19,734	259,174
Japan	1,058	29,575	230	15,917	414	35,260
United Kingdom	13,835	332,551	10,931	258,425	26,640	597,024
Total	17,948	444,307	26,152	401,098	47,363	905,462
Other selenium compounds:						
Belgium-Luxembourg	--	--	--	--	464	35,478
Canada	1,105	3,394	--	--	48	2,400
Germany, Federal Republic of	22	1,443	338	10,351	230	5,324
Japan	1,588	81,559	--	--	--	--
Sweden	123	1,398	--	--	264	6,296
United Kingdom	1,037	44,072	2,631	152,070	1,943	99,668
Total	3,875	131,866	2,969	162,421	2,969	149,166
Grand total	400,658	8,357,564	462,646	9,559,166	495,862	10,108,499

Source: Bureau of the Census; figures adjusted by the Bureau of Mines.

WORLD REVIEW

World consumption of selenium increased by an estimated 10% in 1987 and continued to grow faster than world production. Consumption growth was particularly strong in the United States and China. It was estimated that Chinese imports more than doubled from the 1986 level, making China the fourth largest selenium consumer after the United States, the United Kingdom, and Japan.

In Belgium, a planned expansion of MHO selenium-refining capacity at its Hoboken operations during 1987 was delayed. The expansion from 160 tons per year to an estimated 360 tons per year was rescheduled for completion by yearend 1988. MHO recovered selenium from anode slimes generated at its Olen refinery, principally from imported Zairian copper, and from purchased anode slimes, some of which originated in the United States. Most of the selenium produced was high-purity metal suitable for electronic applications.

Table 14.—Selenium: World refinery production, by country[1]

(Kilograms, contained selenium)

Country[2]	1983	1984	1985	1986[p]	1987[e]
Belgium[e]	r140,000	r180,000	r230,000	250,000	230,000
Canada[3]	266,000	e354,000	361,000	345,000	345,000
Chile	43,869	25,450	50,037	16,267	20,000
Finland	11,172	16,975	14,038	5,693	10,000
India	3,684	4,191	4,850	r e4,800	4,800
Japan	433,122	464,524	496,835	426,567	4481,109
Mexico	24,000	44,000	42,000	23,000	25,000
Peru	19,514	20,758	14,506	12,312	12,000
Sweden	42,000	68,000	46,000	r e50,000	50,000
United States	353,860	253,598	W	W	W
Yugoslavia[e]	e43,720	45,000	46,000	45,000	45,000
Zambia[5]	22,051	17,355	19,490	15,405	4e22,150
Total	r1,402,992	r1,493,851	1,324,756	1,193,744	1,245,059

[e]Estimated. [p]Preliminary. [r]Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

[1]Insofar as possible, data relate to refinery output only; thus, countries that produced selenium contained in copper ores, copper concentrates, blister copper, and/or refinery residues, but did not recover refined selenium from these materials indigenously, were excluded to avoid double counting. Table includes data available through June 10, 1988.

[2]In addition to the countries listed, Australia, the Federal Republic of Germany, and the U.S.S.R. produced refined selenium, but output is not reported, and available information is inadequate for formulation of reliable estimates of output levels. Australia is known to produce selenium in intermediate metallurgical products and has facilities to produce elemental selenium. In addition to having facilities for processing imported anode slimes for the recovery of selenium and precious metals, the United Kingdom has facilities for processing selenium scrap.

[3]The 1983-85 refinery output is from all sources, including imported materials and secondary sources; 1986-87 excludes secondary production.

[4]Reported figure.

[5]Data are for fiscal year ending Mar. 31 of that stated. In addition to refined selenium produced, Zambia exported significant quantities of selenium contained in anode slimes.

TECHNOLOGY

Copper indium diselenide ($CuInSe_2$) continued to draw interest as a thin-film solar-cell material. Research efforts were being directed at improving cell efficiency and building large-area modules suitable for practical application. Although efficiencies of about 12% have been achieved, the U.S. Department of Energy predicts that an efficiency of about 15% will be required to produce cost-effective solar power.[23]

The Fifth International Conference on the Chemistry of Selenium and Tellurium was held in Oak Ridge, TN. Sessions held included those on the organic, physical, and biochemical aspects of selenium, and on selenium films.

The Selenium-Tellurium Development Association Inc., Darien, CT, published a brochure providing background information on selenium as an essential nutrient for animals, humans, and plants. The brochure outlines some of the detrimental effects of selenium deficiency and effective ways of providing selenium to animals whose diets are deficient in selenium.[24]

TELLURIUM[25]

Commercial-grade tellurium (minimum 99% tellurium) and tellurium dioxide were produced by Asarco as byproducts of copper processing at its electrolytic copper refinery at Amarillo, TX. Asarco provided tellurium production data to the Bureau of Mines; however, the data are withheld to avoid disclosing company proprietary data.

Domestic demand for tellurium and its compounds increased by at least 15% in 1987. Most of the demand for commercial-grade material was satisfied by domestic production, but demand for high-purity tellurium was met almost entirely by imports.

The principal use of tellurium was as an alloying metal in free-machining steel and copper. High-purity tellurium was of strategic significance because of its use in mercury-cadmium-telluride, an infrared sensing material for thermal imaging in night vision and navigation systems. Estimated consumption of tellurium, by end-use category, was iron and steel, 58%; nonferrous metals, 20%; chemicals and rubber manufacturing, 15%; other uses, including xerographic and electronic applications, 7%.

Table 15.—U.S. imports for consumption of tellurium, by class and country

Class and country	1985[r]		1986[r]		1987	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Unwrought and waste and scrap:						
Belgium-Luxembourg	5	$5878	47	$1,021	1,041	$32,401
Canada	13,458	453,929	7,159	504,983	4,525	463,462
Germany, Federal Republic of	5	1,404	—	—	5	1,441
Japan	499	29,083	754	43,891	347	38,149
Netherlands	500	9,653	—	—	—	—
Peru	963	18,963	4,863	70,244	—	—
United Kingdom	4,999	107,398	9,000	175,543	2,962	72,904
Total	20,429	626,308	21,823	795,682	8,880	608,357
Compounds:						
Belgium-Luxembourg	907	15,381	10	1,277	—	—
Canada	90	1,904	—	—	(1)	1,879
Germany, Federal Republic of	64	3,369	—	—	133	6,463
Japan	103	10,900	63	7,161	188	9,743
Philippines	9,220	202,483	—	—	—	—
Switzerland	—	—	—	—	7	1,633
United Kingdom	22	5,536	359	76,545	932	114,192
Total	10,406	239,573	432	84,983	1,260	133,910
Salts:						
Germany, Federal Republic of	—	—	8,466	30,397	16,550	64,238
Netherlands	2,400	5,410	—	—	—	—
United Kingdom	—	—	—	—	10	1,355
Total	2,400	5,410	8,466	30,397	16,560	65,593
Grand total	33,235	871,291	30,721	911,062	26,700	807,860

[r]Revised.
[1]Less than 1/2 unit.

Source: Bureau of the Census.

In response to a global production deficit and a drawdown in domestic and world stocks, the domestic producer price of tellurium metal, which had remained stable at about $10 per pound since 1982, rose steadily throughout the year to about $20 per pound at yearend.

Table 16.—Tellurium: World refinery production, by country[1]

(Kilograms, contained tellurium)

Country[2]	1983	1984	1985	1986[p]	1987[e]
Canada[3]	16,000	e21,000	19,000	r e20,000	27,000
Japan	54,800	61,500	65,600	55,600	e53,305
Peru	15,896	14,066	15,007	9,836	10,000
United States	W	W	W	W	W

[e]Estimated [p]Preliminary [r]Revised. W Withheld to avoid disclosing company proprietary data.

[1]Insofar as possible, data relate to refinery output only; thus, countries that produced tellurium contained in copper ores, copper concentrates, blister copper, and/or refinery residues, but did not recover refined tellurium, are excluded to avoid double counting. Table is not totaled because of the exclusion of data from major world producers, notably the U.S.S.R. and the United States. Table includes data available through June 10, 1988.

[2]In addition to the countries listed, Australia, Belgium, the Federal Republic of Germany, and the U.S.S.R. are known to produce refined tellurium, but output is not reported, and available information is inadequate for formulation of reliable estimates of output levels. Moreover, the other major copper-refining nations such as Chile and Zambia may produce refined tellurium, but output in these nations is conjectural.

[3]Refinery output from all sources, including imports and secondary sources.

[4]Reported figure.

THALLIUM[26]

The U.S. demand for thallium during the last 6 years has been met by imports. The small market size and the toxicity of thallium are the principal factors that will continue to influence domestic dependence on foreign sources for the supply of thallium. Based on import data, the domestic consumption of thallium was estimated to be 3,000 pounds in 1987, significantly higher than in 1986. Metal traders reported that the average price of thallium metal in 200-pound lots ranged from $60 per pound for 99.9%-pure thallium metal to about $100 per pound for 99.999%-pure metal, compared with $20 and $65 per pound, respectively, in 1986.

Legislation and Government Programs.—The Superfund Amendments and Reauthorization Act (SARA) of 1986 (Public Law 99-499) extended and amended the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA or Superfund). Certain requirements were established for the EPA and the Agency for Toxic Substances and Disease Register (ATSDR) with regard to hazardous substances that are most commonly found at facilities on the CERCLA National Priorities List (NPL), and which pose the most significant potential threat to human health. Section 110 of SARA amends section 104(i) of CERCLA by establishing requirements for the preparation of (1) a list of hazardous substances found at NPL sites (in order of priority), (2) toxicological profiles of those substances, and (3) a research program to improve or expand the information available on these substances. EPA and ATSDR published the first priority list of 100 hazardous substances on April 17, 1987, in compliance with the law. The list was divided into 4 priority groups of 25 substances each. In this list, thallium was among the hazardous substances of the fourth priority group.[27]

In July, EPA published its final rule on land-disposal restrictions of liquid wastes in response to the Resource Conservation and Recovery Act (RCRA), as amended by Hazardous and Solid Waste Amendments of 1984. The RCRA required EPA to restrict the land disposal of hazardous wastes, containing the so-called California list. The rule prohibited land disposal of liquid wastes containing thallium compounds at concentrations greater than or equal to 130 milligrams per liter, thallium content.[28]

[1]Prepared by J. Roger Loebenstein, physical scientist.

[2]Federal Register. Environmental Protection Agency. Inorganic Arsenicals; Preliminary Determination To Cancel Registration of Pesticide Products Containing Inorganic Arsenicals Registered for Nonwood Preservative Use. V. 52, No. 1, Jan. 2, 1987, pp. 102-140.

[3]U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. Toxicological Profile For Arsenic. Nov. 1987, 130 pp.

[4]Prepared by staff, Branch of Nonferrous Metals.

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[6]Prepared by Thomas O. Llewellyn, physical scientist.

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[8]Where necessary, values have been converted from Belgian francs (BF) to U.S. dollars at the 1987 average exchange rate of BF37.334 = US$1.00.

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[17]Prepared by James B. Hedrick, physical scientist.

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Table 17.—U.S. imports for consumption of thallium, by country

Country	Compounds			Unwrought and waste and scrap	
	Gross weight (pounds)	Content[1] (pounds)	Value	Gross weight (pounds)	Value
1986:					
Belgium-Luxembourg	867	694	$19,223	1,007	$29,661
Canada				2	1,033
France	440	352	8,643		
Germany, Federal Republic of	524	419	28,898		
Japan	22	18	1,414		
Netherlands	(2)	(2)	(2)		
United Kingdom	10	8	2,250		
Total	r1,863	r1,491	r60,428	1,009	30,694
1987:					
Belgium-Luxembourg	237	190	16,670	1,151	23,731
France	220	176	4,573		
Germany, Federal Republic of	485	388	20,929		
United Kingdom	11	9	2,450	1,034	20,756
Total	953	763	44,622	2,185	44,487

rRevised.
[1]Estimated by the Bureau of Mines.
[2]Revised to zero.

Source: Bureau of the Census.

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